

# EXHIBIT 1

# A 140-element Ge Detector Fabricated with Amorphous Ge Blocking Contacts

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## Abstract

A 140-element position-sensitive Ge detector has been fabricated as the prototype detector for the development of a monochromatic computed tomography system using synchrotron radiation. The detector was made in very few processing steps that included the use of amorphous Ge blocking contacts. The fabrication process and the results of testing the detector are described.

## I. INTRODUCTION

Amorphous Ge (a-Ge) deposited on high-purity Ge crystals by sputtering followed by metalization forms low-leakage-current blocking contacts suitable for radiation detector applications [1]. The amorphous Ge contact formation process also provides a simple means of fabricating multi-element Ge detectors for x-ray and  $\gamma$ -ray imaging applications. This technology was used to develop a 140-element Ge linear array detector which served as a prototype detector in a synchrotron-based monochromatic computed tomography (CT) scanner being developed at the X17 superconducting wiggler beamline of the National Synchrotron Light Source, Brookhaven National Laboratory. The system is called Multiple Energy Computed Tomography (MECT) because it uses energy-selective CT methods, such as dual photon absorptiometry and K-edge subtraction technique. Although the detector was used in the current-integration mode for measuring x-ray flux, its characteristics do not exclude its operation, in conjunction with the appropriate electronics, in the photon counting mode for spectrometric measurements.

## II. FABRICATION

The detector was fabricated from a p-type Ge crystal 85 mm long, 21 mm wide and 6 mm thick in the direction of the

incident beam. It was cut from a large diameter Ge boule with the long dimension perpendicular to the crystal growth axis. The net acceptor concentration in the crystal was  $2 \times 10^{10} \text{ cm}^{-3}$ . A 5 mm deep groove was cut from the front side near each end of the crystal. This resulted in two short sections at the ends of the crystal which will be electrically isolated from the active region of the detector during its operation. This allows for ease of handling during processing and for securing the finished detector in the cryostat. The crystal was first lapped, and then chemically etched with a mixture of  $\text{HNO}_3$ :HF at a ratio of 4:1 to remove mechanical damage. Next, the p<sup>+</sup> contact was formed on the back side using B ion implantation (25 keV,  $1 \times 10^{14} / \text{cm}^2$ ). The contact was then metalized with Pd by e-beam evaporation. After masking the p<sup>+</sup> contact with etch-resistance tape, the whole crystal was then given a brief etch, quenched in methanol and then blown dry with nitrogen gas. The crystal was then loaded immediately into an RF sputterer. A 3000 Å thick a-Ge layer was sputter deposited onto the top and side surfaces of the crystal in a gas mixture of 93% argon and 7% hydrogen at a pressure of 7 microns. Contact elements were formed over the a-Ge film on the front surface of the device by Au evaporation through a shadow mask. The contact elements were each 0.3 mm wide and 12 mm long, with a 0.5 mm center-to-center spacing (i.e., a 0.2 mm gap between adjacent elements). The Au layer was also about 3000 Å thick. Next, a ~3 mm wide guard electrode surrounding the contact strips was produced by performing another Au evaporation through a different set of masks. It should be pointed out that it is possible to deposit both the guard ring and the strips in a single evaporation step using appropriately designed shadow masks.

Figure 1 shows schematically the structure of the detector in a cross-sectional view. The areas of the contact elements are defined by the metalization while the blocking junctions are located at the a-Ge/crystalline Ge interface. The portion of the a-Ge film which was not covered with metal, i.e., the area between electrodes and the side surfaces, acts as a passivation layer. The resistivity of the a-Ge deposited on a glass slide under the same sputter conditions was measured to be  $\sim 10^4 \Omega \cdot \text{cm}$  at 77 K. Based on this value and the aspect ratio of the a-Ge film on this detector, the resistance of the film perpendicular to a contact element is calculated to be  $8 \times 10^4 \Omega$ , while the resistance between a pair of adjacent electrodes is  $\sim 6 \times 10^4 \Omega$ .

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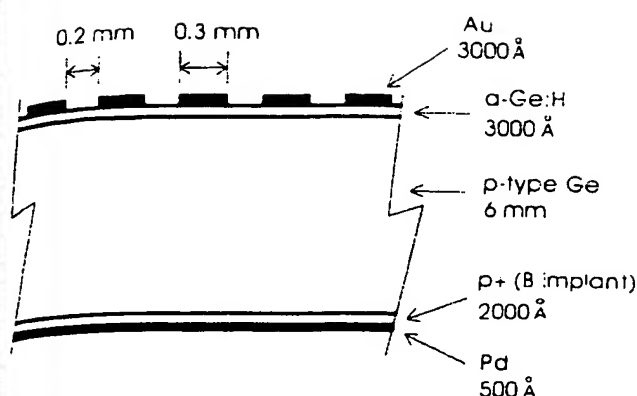


Fig. 1 Schematic structure of the 140-element Ge detector.

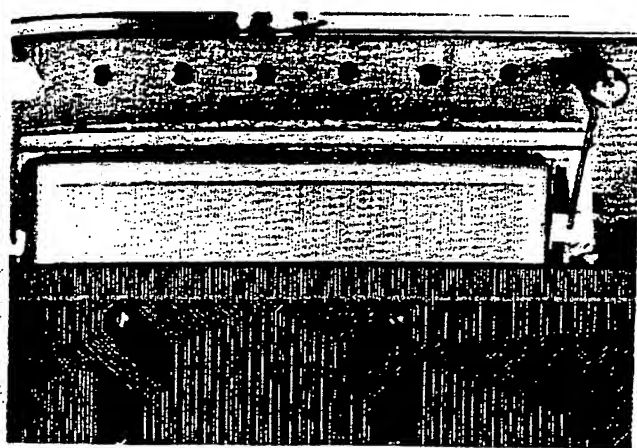


Fig. 2 Detector wire bonded to fan-out circuit board.

### III. MECHANICAL ARRANGEMENT

The detector was secured using spring clips onto a boron de block which in turn is mounted on top of a copper block. Indium foils were used at the mechanical interfaces to improve thermal conduction and to provide an electrical connection to the p<sup>+</sup> contact. Ultrasonic aluminum wire bonding provided electrical connections between the contact strips and the circuit traces on a fan-out circuit board that was also mounted on the copper block (Fig. 2). The detector assembly was then affixed onto the cold plate of the cryostat (Fig. 3). Electrical connections from the circuit board to the exterior of the cryostat were made via a connector attached to a flexible circuit foil which passed through an epoxy seal in the cryostat wall. This circuit foil terminated with a set of connectors outside the cryostat. The high-voltage connection to the p<sup>+</sup> contact was made via a separate feedthrough.

### IV. TESTING

The detector was tested for depletion voltage, leakage current and inter-electrode impedance after being cooled to near

liquid nitrogen temperature. Capacitance-voltage measurements indicated that the detector was fully depleted at 400 V. Except for nine detector elements which showed high leakage currents, ranging from  $10^{-10}$  to  $10^{-6}$  A, each of the other elements exhibited leakage currents less than 1 pA at 1000 V bias. The guard ring had a leakage current of  $8 \times 10^{-10}$  A. The inter-electrode impedance was measured by varying the voltage on a contact strip over a small range near ground potential ( $\pm 0.1$  V) and measuring the change in current of an adjacent strip which is held at ground potential. The resistance was found to be  $\sim 10^{11} \Omega$ . The detector has been used in the prototype MECT system which produced images of phantoms and small animals [2]. The viewing frequency used in these imaging measurements was 480 Hz.

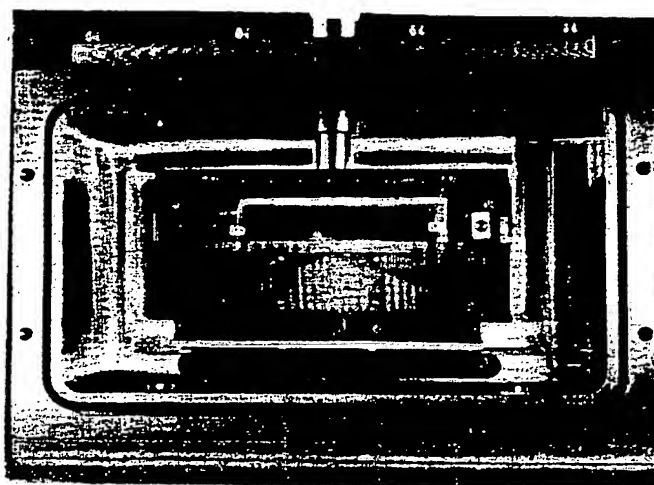


Fig. 3 Detector assembly mounted in a cryostat.

### V. DISCUSSION

An evaluation of the prototype 140-element Ge detector showed that small-feature multi-element Ge detectors can be fabricated utilizing a-Ge blocking contacts. It is noteworthy that, using this technique, only three steps are required to make such detectors, and that all the processing steps can be carried out at room temperature. Damage caused by less-than-optimal wire bonding was the likely cause of the high leakage current observed for several of the contact elements in the present detector. The very low leakage currents observed from the rest of the elements suggest that, with improved wire bonding conditions, it should be possible to produce detectors with zero defects.

Depending on the application, the resistance of the a-Ge layer under the metal contacts may introduce a significant amount of electrical noise. In the present case, the resistance beneath each metal strip is about  $8 \times 10^4 \Omega$ , corresponding to a Johnson voltage noise of  $18 \text{ nV/Hz}^{1/2}$  which is well below the noise of the current-sensing electronic system used. For applications requiring lower level of noise, a thinner layer of a-Ge can be used to reduce the resistance and thus the noise.

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Contacts with a-Ge layers as thin as 300 Å have been successfully fabricated. At high measurement frequencies, such as those encountered in pulse counting spectrometric applications, the noise is shunted by the high capacitance of the thin a-Ge layer and can become negligible [3].

## VI. REFERENCES

- [1] P. N. Luke, C. P. Cork, N. W. Madden, C. S. Rossington and M. F. Wesela, "Amorphous Ge Bipolar Blocking Contacts on Ge detectors," *IEEE Trans. Nucl. Sci.*, vol. 39, no. 4, pp. 590-594, Aug. 1992.
- [2] F. A. Dilmanian, H. Rarback, E. Nachaliel, M. Rivers, W. C. Thomlinson, R. Appel, L. D. Chapman, R. F. Garrett, P. N. Luke, M. H. Miller, R. Pehl, T. Oversluizen, D. N. Slatkin, P. Spanne, S. Spector and A. C. Thompson, "CT Imaging of Small Animals using Monochromatic Synchrotron X-Rays," in *Conference Record of the 1992 IEEE Nuclear Science Symposium and Medical Imaging Conference*, vol. 2, Orlando, FL, October 1992, pp. 1298-1300.
- [3] P. N. Luke, C. S. Rossington and M. F. Wesela, "Low Energy X-Ray Response of Germanium Detectors with Amorphous Germanium Entrance Contacts," this conference.